

# TWO-PHOTON PROCESSES IN TWO-NUCLEON SYSTEMS AS A TOOL OF SEARCHING FOR EXOTIC SIX-QUARK RESONANCES<sup>1</sup>

S.B. GERASIMOV

*Bogoliubov Laboratory of Theoretical Physics,  
Joint Institute for Nuclear Research, Dubna, 141980 Russia*

## Abstract

The reaction  $pp \rightarrow pp2\gamma$ , proposed earlier to probe for the NN-decoupled dibaryon resonances, has been studied by the DIB2 $\gamma$  Collaboration (JINR) and their preliminary data seem to give evidence for the resonance effect at about 1920 MeV. We discuss some other two-photon processes: the double radiative capture reaction in pionic deuterium, photoabsorption sum rules and the nuclear Compton scattering, which we consider to be feasible for further test and investigation of possible low-lying, exotic six-quark states.

## 1 Introduction

The experimental discovery of dinucleon (or, generally, multibaryon) resonances not decaying into two (or more) nucleons in the ground state would be one of the most spectacular explications of nonpotential, nonnucleon degrees of freedom and would imply important consequences in further development of nuclear and hadron matter physics. The nonstrange NN-decoupled dibaryons with small widths appear to be the most promising and interesting candidates for experimental searches. Among available candidates to be confirmed (or rejected) in future dedicated and, hopefully, more sensitive experiments we wish to mention the indications of the existence of a narrow  $d'$  dibaryon slightly above the  $\pi NN$  threshold, coming from data on pion double charge exchange on nuclei [1], and  $d_1^*$ -enhancement below  $\pi NN$ -threshold, seen in preliminary data on the proton-proton double bremsstrahlung at 200 MeV [2].

It would be of undoubtedly interest to try different reactions to search for these states. With the pion absorption reactions, the presumed  $d_1^*$ -dibaryon can be excited via strong interactions only on the three- (or more) nucleon states. With the deuteron targets most thoroughly investigated and most easy to deal with theoretically, we have to resort to radiative processes.

This report aims at drawing attention to the real feasibility and suitability of study of radiation reactions such as  $\pi(\mu)$ -meson capture processes in the deuterium mesoatoms and the photon-deuteron scattering or analysis of integral characteristics of corresponding photoabsorption cross sections for the sake of inquiry on possible nucleon and dinucleon exotics.

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## 2 The $2\gamma$ -production in $pp$ -interactions: indications from data

For the sake of completeness we remind some points referring to the double photon emission reaction. In refs.[3, 4] the process  $pp \rightarrow \gamma^2B \rightarrow pp\gamma\gamma$  has been advocated to provide unique possibilities of searching for and investigating narrow NN-decoupled dibaryon resonances with masses below the pion production threshold. The method of searching for these narrow dibaryon resonances is based on the measurement of the photon energy distribution in the  $pp \rightarrow pp\gamma\gamma$  reaction by detecting both photons in coincidence. The narrow dibaryons, if they exist, should be seen as sharp  $\gamma$ -lines against a smooth background due to the photons from the radiative resonance decays( $^2B \rightarrow \gamma pp$ ) and double  $pp$ -bremsstrahlung with an anticipated good signal-to-background ratio. The position of this line depends on the energy of the incident proton and the resonance mass  $M_B$ . Its width is determined by the total width of resonance  $\Gamma_{tot}$  and energy resolutions of the experimental setup. The  $\gamma$ -ray energy spectrum for the  $pp \rightarrow pp\gamma\gamma$  reaction at the proton energy  $\sim 200$  MeV has been measured in ref.[2]. A distinct enhancement at the photon energy about 42 MeV was observed in measured energy spectrum. It can be interpreted as a signal due to the narrow exotic dibaryon  $^2B$  formation and decay in the  $pp \rightarrow \gamma^2B \rightarrow pp\gamma\gamma$  processes. Distribution of the dibaryon mass obtained under this assumption shows a narrow peak with mass  $M_B=1923.5\pm4.5$  MeV and width FWHM= $31.3\pm5.0$  MeV. The statistical significance of this peak exceeds  $8\sigma$ . In ref.[6], the radiative transition  $d_1^*(IJ^P = 11^+) \rightarrow \gamma pp$  or the inverse reaction  $pp \rightarrow \gamma d_1^*$  has been considered as a two-step process, where the presumably lowest  $pp$ -decoupled state with the  $J^P = 1^+$ , tentatively called  $d_1^*$ , is coupled with the initial or final hadron states through the intermediate  $N\Delta$ -state with the same quantum numbers. The "Δ" - symbol may be referred also to the virtual  $\pi N$ -complex with quantum numbers of the  $\Delta(1232)$ -resonance but a different invariant mass. The  $d_1^*\Delta N$ -vertex is described by a simple form of the quasi-two-body wave function, for which the Hulthen-type radial dependence was chosen by analogy with the deuteron radial wave function:

$$R(r) = N \frac{1}{r} \exp(-\alpha r) (1 - \exp(-\beta(r - r_c))) \quad (1)$$

where  $N$  is the normalization constant,  $\alpha = \sqrt{2M_{red}\varepsilon_1}$ ,  $\varepsilon_1 = M + M_\Delta - M_{d_1^*}$ ,  $M_{red}^{-1} = M^{-1} + M_\Delta^{-1}$ ,  $\beta = 5.4 fm^{-1}$ ,  $r_c = .5 fm$  and  $R(r) = 0$  for  $r \leq r_c$  is understood. The second factor in Eq.(2), representing the behavior of wave function in the "interior" region outside the hard core with the radius of  $r_c = .5 fm$  is taken quite similar to the deuteron case. Taking  $M_{d_1^*} \simeq 1920$  MeV for granted, the transition magnetic moment  $\mu(p\Delta^+) = 2\sqrt{2}/3\mu(p)$  according to the  $SU(6)$ -symmetry and plane waves for initial protons, we get an estimation

$$\left(\frac{d\sigma}{d\Omega_\gamma}\right)_{c.m.} \simeq \frac{\alpha(W - M_{d_1^*})^3 (\mu(p)I(q))^2}{9Mq} \simeq 40 \frac{nb}{sr} \quad (2)$$

$$I(q) = \int_{r_c}^{\infty} dr r^2 R(r) \frac{\sin(qr)}{qr}$$

where  $\alpha = 1/137$ ,  $\mu(p) = 2.79$ ,  $q \simeq \sqrt{MT_{lab}/2}$ ,  $M$  is the mass of the proton. It turns out justified to neglect the retardation corrections, i.e. we are using the long-wave

approximation for the matrix element of magnetic-dipole transition. Further, the result does not depend strongly on variation of the "effective" mass  $M_\Delta$  from  $M + m_\pi$  to  $M_\Delta = 1232\text{MeV}$ . With the integrated luminosity  $L = 10^{37}\text{cm}^{-2}$ , the data gave about 130 events after integration over energies of both photons in the interval  $10 \leq \omega_i \leq 100\text{MeV}$ . Assuming the spherical-symmetric distribution of photons, we obtain an estimate of the cross section for one of photons to be registered in the element of solid angle

$$\frac{d\sigma}{d\Omega_\gamma} \simeq 4\pi \left( \frac{d\sigma}{d\Omega_{\gamma_1} d\Omega_{\gamma_2}} \right)_{exp} \simeq 65 \frac{\text{nb}}{\text{sr}} \quad (3)$$

By definition, this is the quantity which should be confronted with Eq.(2) and we estimate the result of this comparison as a reasonable one.

Concerning the negative result of the recent experiment at CELSIUS [7], we note that this experiment was not a dedicated one for a search of the two-photon production in proton-proton interactions, but, rather, it was optimised for investigation of the  $pp \rightarrow pp\gamma$  reaction. Therefore, in our opinion, the immediate relation of their upper bound on the exotic dibaryon production cross section with the result of ref.[2] still needs to be developed.

### 3 Meson capture from mesoatomic states and possible exotics

In what follows we concentrate mainly on the radiative pion capture processes because they are experimentally easier to investigate. This proposal is not entirely new. In fact, there is the work devoted to search for the exotic isotensor (with the isospin  $I = 2$ ) dibaryon resonance done at TRIUMF [5]. We, however, propose to look for a rather specific object, which seemed to be beyond the design and kinematics area covered by the abovementioned experiment. Furthermore we rely on what can be taken into account from an analysis [6] of situation connected with the double bremsstrahlung experiment [2].

A few remarks are to be made about quantum numbers of the mentioned candidates. The isospin 0 assignment for the  $d'$  resonance with quantum numbers  $J^P = 0^-$  was motivated by calculations within a QCD string model, while the isospin 2 assignment was made in [8] on the basis of the  $\pi NN$  bound system molel and within the Skyrme model approach. With the  $d'$  quantum numbers  $0^-$  and isospin 2, the dominant isobar in the pion-nucleon sub-system is  $P_{33}$  or  $\Delta$ , so that nucleon and isobar have relative orbital angular momentum 1 and total spin 1. With the isospin 0 assumed, the dominant pion-nucleon sub-system in three-body model is the  $S_{11}$  isobar and the nucleon-isobar quasi-two-body system has the relative orbital momentum and total spin both equl to 0.

For the  $d_1^*$ -state, presumably seen in the proton-proton double bremsstrahlung reaction below the pion threshold, we suggest the  $\Delta N$  with relative orbital angular momentum 0 as the dominant cluster configuration. Of the possible values 1 or 2 for spin and isospin, we consider the unit spin/isospin value as more natural for the state with lowest mass. In this case the  $NN$  decay channel is strictly forbidden by the exclusion principle, and if the  $\pi NN$  decay mode is kinematically forbidden we have the radiative decay as the only possible one with the width of  $\sim \text{KeV}$  scale. It might, however, be that the isospin 2 assigment for  $d_1^*$  is dynamically preferable, like in the case of the  $d'$ -state mentioned above. In that case the

$d_1^* \rightarrow NN$  decay mode is possible though strongly suppressed being of order  $O(\alpha^2)$  versus the radiative decay of the order  $O(\alpha)$ . To discriminate between two options ( $I = 0$  vs  $2$ ), it is important to study several reactions differently sensitive to different isospin values. It is with this feature in view, that we propose to make use of the double radiative capture process in the pionic deuterium in addition to the nucleon-nucleon double bremsstrahlung reactions. As will be seen in the next section, the transition operator between the deuteron and dibaryon resonance state vectors is transformed, by construction within the assumed model, as the isovector under rotations in the isospin space. This means that, unlike the proton-proton double bremsstrahlung reaction, the narrow dibaryon will not be excited in the radiative pion capture on the isosinglet deuteron if the isospin of this resonance equals 2.

The branching ratios of different  $\pi^-$ -capture channels in the pionic deuterium:  $\pi^-d \rightarrow nn(.7375 \pm .0027)$ ,  $nn\gamma(.2606 \pm .0027)$ ,  $nne^+e^-((1,81 \pm .02) \cdot 10^{-3})$ ,  $nn\pi^0((1.45 \pm .09) \cdot 10^{-4})$ , measured at TRIUMF [9, 10], give the total probability  $w(\pi^-d \rightarrow X(measured)) = 1.000 \pm .038$ . Therefore, the upper bound of still undetected channels is not much larger than  $\simeq .38\%$ , well within capability of measurements if there is good signature. We estimate which could be the yield of two  $\gamma$ 's from consequent processes of the radiative excitation and de-excitation of the exotic  $d_1^*(1920)$ , presumably seen in the proton-proton double bremsstrahlung:

$$(\pi^-d)_{atom} \rightarrow \gamma d_1^* \rightarrow \gamma\gamma X \quad (4)$$

The radiative decay branching ratio  $Br(d_1^* \rightarrow \gamma X) = 1$ , hence we need to calculate only the  $d_1^*$ -excitation probability, i.e. the transition  $(\pi^-d)_{atom} \rightarrow \gamma d_1^*(1920)$ . The radiated photon takes off the energy  $\omega = 92.9 MeV$  thus enabling the resonance state to be on its mass-shell. As a hint for possible qualitative estimate we note that the probability of ordinary radiationless  $\pi^-$ -capture  $w((\pi^-d)_{atom} \rightarrow nn)$  is only three times as large as that of the radiation capture. This is indication of the dominantly short-range nucleon-nucleon interaction dynamics involved in a pure strong capture channel, resulting in a poor overlap with the deuteron wave function having characteristically large spatial extensions. An essential feature of mechanisms of both the ordinary  $NN$ -channel [11] and the assumed  $d_1^*$ -excitation is the appearance of the  $N\Delta$ -configuration in an intermediate state of reactions considered. So, it seems reasonable to expect that

$$BR((\pi^-d)_{atom} \rightarrow \gamma d_1^*) \sim \alpha_{em} BR((\pi^-d)_{atom} \rightarrow nn) \simeq .74/137 \simeq .5\%. \quad (5)$$

More quantitative estimation is made within a model used previously [6] for the reaction  $pp \rightarrow \gamma d_1^*$ . Namely, we assume the reaction mechanism when  $\pi^-$  is radiatively captured by a nucleon to form the (virtual)  $\Delta$  that, in turn, is associated with a spectator nucleon to form the  $d_1^*(1920)$ -resonance.

As in the case of our estimation of the  $pp \rightarrow pp2\gamma$  cross section in the previous section, we adopt the explicitly phenomenological approach in calculation of the pion capture rate.

Having in mind the completeness of colourless hadron states, we estimate the probability of the radiative transition  $(\pi^-d)_{atom} \rightarrow \gamma d_1^*(IJ^P = 11^+)$  as a two-step process, where the presumably lowest  $NN$ -decoupled state with the  $J^P = 1^+$ , we are calling  $d_1^*$ , is coupled with the initial or final hadron states through the intermediate  $N\Delta$ -state with the same quantum numbers. We make use of standard formulas for a capture from atomic states following from the assumption that the hadronic reaction is much shorter in range

than the atomic orbit radii. The rate is, schematically,

$$w(L = 0 \text{ atomic state}) \sim |\psi(0)|^2 |\langle f | T_{\pi\gamma}(\vec{q}) | i \rangle|^2 \quad (6)$$

where  $\psi(r)$  is the  $L = 0$  pionic atom wave function,  $\langle f | T_{\pi\gamma}(\vec{q}) | i \rangle$  is the amplitude of the reaction  $\pi(\vec{q}) + N \rightarrow \gamma + \Delta$  with the free plane wave of a pion with momentum  $\vec{q} \simeq 0$ , taken between the initial  $NN$ -bound state (i.e. the deuteron) and the final  $\Delta N$ -state (i.e. the  $d_1^*$ -resonance). As we deal with the threshold-type process, we proceed with keeping only the seagull Feynman graph, approximating the  $N\pi\gamma\Delta$  block (the corresponding  $N\gamma\pi N$ -graph is known to give the low-energy Kroll-Ruderman threshold theorem for the charged pion photoproduction on nucleons). The  $\Delta N\pi$ -coupling constant is defined by the  $SU(6)$  symmetry through the known pion-nucleon coupling. It seems justified also to neglect the retardation corrections, i.e. we are using the long-wave approximation for the matrix element of electric-dipole radiative transition. The  $d_1^*\Delta N$ -vertex is described by a simple form of the quasi-two-body wave function, for which the Hulthen-type radial dependence (1) was chosen by analogy with the deuteron radial wave function. The radial part of the deuteron wave function is obtained from (1) when  $\varepsilon_1 = M + M_\Delta - M_{d_1^*}$  is replaced by  $\varepsilon = 2.23$  MeV. Taking the measured value of the total width  $\Gamma_{tot} \simeq 1$  eV [12] for the  $1S$ -level of pionic deuterium, we obtain the following estimation for the (unobserved) decay channel

$$BR((\pi^- p)_{atom} \rightarrow \gamma d_1^* \rightarrow \gamma\gamma X)_{1S-state} = .6\%, \quad (7)$$

surprisingly close to scale estimate (2) and not embarrassingly distant from the experimental bound  $\leq .4\%$ , despite the adopted approximations being crude. We note also, that our result does not depend strongly on variation of the "effective" mass  $M_\Delta$  from  $M + m_\pi$  to  $M_\Delta = 1232$  MeV, ( $M = 939$  MeV,  $m_\pi = 139$  MeV being masses of the nucleon and pion), if  $M_{d_1^*} = 1920$  MeV is taken for granted. To get an estimate of the background non-resonance  $2\gamma$ -emission rate, we take

$$BR(\pi^- d \rightarrow 2\gamma/1\gamma) \simeq BR(\pi^- p \rightarrow 2\gamma/1\gamma) \simeq 1.3 \times 10^{-4}, \quad (8)$$

where the corresponding ratio for the pionic hydrogen was calculated by Beder [13]. We have then

$$BR((\pi^- d)_{atom} \rightarrow \gamma\gamma X)_{nonres} \simeq BR((\pi^- d)_{atom} \rightarrow \gamma nn) \times 1.3 \cdot 10^{-4} \simeq 3.4 \cdot 10^{-5} \quad (9)$$

which is considerably lower than the estimated resonance contribution. We point out also a qualitative difference of the  $\gamma_1 - \gamma_2$  opening angle  $\theta_{12}$  distribution following from the resonance and nonresonance mechanisms. In the resonance excitation mechanism, we have emission of the electric-dipole photon at the  $d_1^*$ -resonance excitation vertex and the magnetic-dipole photon emission in the  $d_1 \rightarrow \gamma nn$  transition, the nn-pair being mainly in the  ${}^1S_0$ -state. The polarization structure of the matrix element

$$T(\vec{\epsilon}_d, \vec{\epsilon}_1(k_1), \vec{\epsilon}_2(k_2), \dots) \sim a_1([\vec{\epsilon}_d \times \vec{\epsilon}_1] \cdot [\vec{\epsilon}_2 \times \vec{k}_2]) + (1 \leftrightarrow 2) \quad (10)$$

gives after the squaring and summation over polarizations

$$W(\theta_{12}, \varphi) = \frac{3}{16\pi} \cdot (1 + \frac{1}{2} \cdot \sin^2 \theta_{12}) \quad (11)$$

which has a maximum at  $\theta_{12} = 90^\circ$ , while the corresponding distribution in the  $\pi^- p \rightarrow 2\gamma n$  reaction, calculated by Beder [13], and, by our assumption based on the impulse approximation, also in the  $(\pi^- d)_{nonres} \rightarrow \gamma\gamma X$ -reaction, shows a shallow minimum at  $\theta_{12} = 90^\circ$ .

It can be noted in this respect that a recent calculation [14] of the  $\theta_{12}$ -distribution in reactions  $\pi^- A \rightarrow 2\gamma X$ , ( $A = {}^9 Be, {}^{12} C$ ) approximately agrees with experiment [15, 16] for angles larger than  $90^\circ$  but for  $\theta_{12} \leq 90^\circ$  the calculations are consistently lower than data. A possible role of the exotic resonance excitation is suggestive here, but for a more quantitative estimation one has to take into account a number of very important many-body effects: the Pauli blocking, Fermi-motion smearing, collision broadening of the resonance propagating in nuclear matter. Indeed, each inelastic  $d_1^* N$ -collision can transform the "Δ-part" of the resonance into a nucleon via isovector, spin-dependent forces transmitted by pi- and rho-mesons, thus giving rise to a new decay channel  $d_1^* N \rightarrow 3N$ .

Qualitatively, instead of  $\Gamma_{tot}^{free}(d_1^*) = \Gamma_{rad}(d_1^*) \simeq .5$  KeV we are led to use  $\Gamma_{tot}^{matter}(d_1^*) \simeq \rho \cdot v \cdot \sigma_{inel}(d_1^* N)$ , and for  $\rho \simeq .17 fm^{-3}$ ,  $v = .2$  and  $\sigma_{inel} \simeq 1$  mb, we get  $\Gamma_{tot}^{matter}(d_1^*)$  enhanced by 3 orders of magnitude as compared to  $\Gamma_{tot}^{free}$ . That leads to  $BR(\pi^- A \rightarrow 2\gamma X)$  of the order  $\leq 10^{-5}$  in accord with measurements [15, 16]. To conclude this section, we are tempted to mention that the  $\gamma$ -spectra in radiative pionic deuterium decays can, in principle, test narrow baryon exotics of the type claimed in ref. [17], where the evidence was presented for three narrow baryon states with masses 1004, 1044 and 1094 MeV. The first two of them are within reach of pionic mesoatoms studies.

Our conclusion to this section is: In addition to the planned [18] measurements of processes  $\pi^- p \rightarrow 2\gamma n$  and double photon capture on complex nuclei [19], the radiative capture processes in pionic deuterium as well as the continuum pion energy reactions  $\pi^\pm d \rightarrow \gamma(2\gamma)NN$  well deserve a devoted study being a perspective source of potentially very important information.

## 4 Photoexcitation of two-nucleon exotics in nuclei: the local and integral effects

The contributions of possible  $NN$ -decoupled dibaryon resonances to the photon-deuteron processes like  $\gamma d \rightarrow \gamma d(\gamma pn)$ ,  $\gamma d \rightarrow \pi^- \gamma pp$  have earlier been considered in ref.[20]. The emphasis and most of the numerical estimations were made there for the isoscalar resonances with the quantum numbers  $I = 0, J^P = 0^\pm, 1^-$ , while in this section we shall focus on the  $d_1^*(I = 1, J^P = 1^+)$ -resonance and all illustrative numerical estimations are based on the specific dynamical model with input characteristics extracted from available data [2]. As far as  $\Gamma_{tot} = \Gamma_{rad}$ , the value of the  $\gamma d$  elastic scattering cross section is huge at the resonance value of photon energy  $\omega \simeq 45$  MeV, if we take  $M_{d_1^*} = 1920$  MeV. The theoretical Breit-Wigner cross section with a very small width will then look like a kind of the "δ-function"-distribution, while in reality one can observe a much smoother curve due to the finite initial photon energy spread and finite energy resolution of a detector. Nevertheless, with the use of extremely high monochromaticity beams, which can, in principle, be provided by the laser devices, the effect of the supernarrow resonance excitation should be quite spectacular. The off-mass-shell  $d_1^*$  contribution to spin-independent amplitudes of the  $\gamma d$  scattering can qualitatively be estimated through the dynamical (magnetic)

polarizability

$$\Delta\beta(\omega) \simeq \frac{\omega_r^2 \Delta\beta_{stat}}{\omega_r^2 - \omega^2}, \quad (12)$$

$$\beta_{stat} \simeq \frac{1}{2\pi^2} \int \frac{d\omega \sigma_{res}^{M1}(\omega)}{\omega^2} \simeq 2 \cdot 10^{-4} fm^3, \quad (13)$$

where the magnetic-dipole  $d_1^*$ - photo-excitation cross section,  $\sigma_{res}^{M1}$ , is approximated by the Breit-Wigner formula with  $\Gamma(d_1^* \rightarrow \gamma d) \simeq .2$  KeV, and  $\omega_r = (M_{d_1^*}^2 - M_d^2)/2M_d$  with  $M_{d_1^*} \simeq 1920$  MeV. For  $\omega < \omega_r$  ( $\omega > \omega_r$ )  $\Delta\beta(\omega)$  is positive (negative), thus contributing to the paramagnetic (diamagnetic) part of the polarizability coefficient. Correspondingly, the maximum effect on the differential cross section of the  $\gamma d$ - scattering due to  $\Delta\beta(\omega) \neq 0$  will then be seen via its interference with the leading electric-dipole nuclear amplitudes in photon scattering into the forward (backward) direction. In the interval of photon energies 50 – 70 MeV, the dynamical polarizability due to the exotic  $d_1^*(1920)$ -resonance has the same order of magnitude as electromagnetic polarizabilities of nucleons. Hence, the interpretation of experiments on measurements of nucleon polarizabilities from the deuteron Compton scattering may be influenced considerably by the presence of low-lying, exotically-narrow six-quark resonance(s). More detailed investigation of these questions along the line, *e.g.*, of the approach of ref.[21] is worthwhile in view of experiments planned in Sweden and Canada ( referred in [21]). In the Compton scattering on heavy nuclei, the smearing effects due to Fermi-motion of correlated nucleon pairs and collision broadening of the resonance width have to be taken into account and they wash out the sharp resonance, but the average enhancement of the cross section due to possible dibaryon resonance excitation in the intermediate state is expected to be the same. More careful scanning of the photon energy interval around 40 – 50 MeV in the  $\gamma Pb$  - scattering at large ( $\sim 150^\circ$ ) seems to be worthwhile because the Mainz data [22] may give a hint of a weak "shoulder" over smooth background (Fig.16(d) in ref.[22]).

Concerning characteristics of the spin dependence of nuclear photoabsorption, we mention a possible exotic dibaryon contribution to the polarized photon - hadron sum rule , which was derived for hadrons of any spin [23] and has started to be applied to nucleons and lightest nuclei [25] since long time ago ( for a recent review see [24] and references therein). The specific feature of the polarized photon - deuteron sum rule is the small value of the left-hand side of the sum rule ( $\sim (\mu_d - Q_d/M_d)^2$ ), where  $\mu_d(Q_d)$  is the deuteron magnetic moment (electric charge), which should be balanced by very strong compensation of a large negative value of the integral over deuteron photodisintegration cross sections below the pion photoproduction threshold [25],[26] and equally large positive value of the rest integral over higher energies in the right-hand side of the same sum rule. Possible  $d_1^*$  - excitation is immersed into photodisintegration region but it can easily escape detection due to its extreme narrowness. We just mention here that with the assumed  $d_1^*$  - structure parameters its contribution to the deuteron sum rule is about  $-10 \mu b$ , which is of the order of calculated difference between two above-mentioned and, individually, much larger entries. To conclude this section: Of indispensable value for direct check of low-lying exotic dibaryons with isospin  $I < 2$  there would be scanning of the elastic  $\gamma d$ -scattering cross section with tagged photons in the interval of 40 – 50 MeV and with as good energy resolution as possible.

## 5 Remarks

We conclude with the following remarks.

1. Among theoretical models predicting dibaryon resonances with different masses there is one giving the state with the  $IJ^P = 11^+$  and the mass value ( $\sim 1940\text{MeV}$ ) surprisingly close to the value ( $\simeq 1920\text{MeV}$ ) extracted from the observed maximum of the  $pp \rightarrow pp2\gamma$ -reaction. This is the chiral soliton model applied to the sector with the baryon number  $B = 2$  [27]. The theoretical uncertainty at the level of  $\pm 30\text{MeV}$  might be taken here because the model gives this numerical (unrealistic) value for the mass difference of the deuteron and the singlet level. The absence of this (and some other) exotic,  $NN$ -decoupled states was claimed to lead to definite restrictions on the applicability of the chiral soliton approach in the baryon number  $B > 1$  - sector. However the cited radiative width of the order  $\sim O(eV)$  [27] looks much lower compared to our estimate following from the  $N(\pi N)_{33}$  - or  $N\Delta_{eff}$  - cluster model [6] we have used in this work.

2. Continuation of experiments dealing with closely related processes such as the deuteron Compton scattering and the double radiative pion-capture or radiative muon-capture in deuterium mesoatoms would be very helpful not only as a different area of checking the very existence of exotic dibaryons, but also as a means to discriminate between possible values of their isospin.

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